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Podhradem Interstadial; A critical review of the middle and late MIS 3 (Denekamp, Hengelo) in Moravia, Czech Republic

Lenka Lisá [a,*], Petr Neruda [b], Zdeňka Nerudová [c], Ladislav Nejman [d,e]

[a] Institute of Geology CAS, Rozvojova 269, Prague 6, 165 00, Czech Republic
[b] Anthropos Institute of Moravian Museum, Zelný trh 6, Brno, 659 37, Czech Republic
[c] Centre for Cultural Anthropology, Moravian Museum, Zelný trh 6, Brno, 659 37, Czech Republic
[d] School of Philosophical and Historical Inquiry, The University of Sydney, Sydney, Australia
[e] School of Archaeology and Anthropology, Australian National University, Canberra, ACT, 0200, Australia

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ABSTRACT

Knowledge of global climatic fluctuations in the last glacial period has been instrumental for understanding evolution of the landscape and human behavior. Regional environmental responses to these fluctuations are influenced by many factors and their identification at the regional level usually results in local chronostratigraphic schemes. The term Podhradem Interstadial was introduced to the scientific community in 1966 on the basis of the results of an interdisciplinary excavation at Pod Hradem Cave in the Moravian Karst (Czech Republic). Brown soil horizons preserved in the upper part of the section were interpreted as evidence for a warmer period in the last glacial period. The upper part of this soil complex contained fauna remains and lithic artefacts indirectly dated to the time range 28.2–33.3 ^{14}C ka BP. Although based on contemporary state of knowledge, the Podhradem Interstadial had no stratigraphic equivalent in loess profiles of former Czechoslovakia and Lower Austria, the term was occasionally used in the European literature. The new interdisciplinary excavations of Pod Hradem Cave (2011–2016) yielded new data, which we use to re-evaluate the concept of the Podhradem Interstadial. In light of the new results, it seems that the original definition of Podhradem Interstadial has a number of problems. It does not fulfill stratigraphic standards and it is evident that the contemporaneous sediments differ lithologically in different parts of the cave. Furthermore, when we take into account the current availability of sophisticated climatostratigraphic schemes for the MIS 3 period, the continuing use of the Podhradem Interstadial should be considered redundant.

1. Introduction

The Middle Weichselian denominated as MIS 3 (dating varies in the time-span 60–24 ka BP, for summary of different views see Bradley, 2015) is characterized by frequent and abrupt climatic changes of high amplitude, represented by repetitive fluctuations in climate systems, e.g. Heinrich system, Dansgaard–Oeschger cycles (D–O), or Greenland stadials (GS)/interstadials (GI) (Bond et al., 1992; Dansgaard et al., 1993; Gkinis et al., 2014; Huber et al., 2005; Johnsen and Dansgaard, 1992; Kindler et al., 2013; NGRIPm., 2004; Rousseau et al., 2017; Ruth et al., 2003), when the abrupt warming episodes in Greenland lead to cooling in Antarctica and the cold periods in Greenland coincide with rising temperatures in Antartica (Lemieux-Dudon et al., 2010). This knowledge is revealed from high-resolution deep sea and ice core oxygen isotope records, and is more or less generally valid for most of the planet. For example, the warming in Greenland is coincident with warmer, wetter conditions in Europe associated with more intensive soil development (Genty et al., 2003) and little or decreased dust deposition (Rousseau et al., 2017; Sima et al., 2009, 2013), an enhanced summer monsoon in the northwest Indian Ocean (Pausata et al., 2011; Schulz et al., 1998), a northward shift of precipitation belts in the Cariaco Basin (Peterson and Schwing, 2003), aridity in the southwestern United States (Wagner et al., 2010) and changes in ocean ventilation off the Santa Barbara shore, California (Hendy et al., 2002). Concerning the dust deposition it should be noted, that Sirocko et al. (2013, 2016; 2005) recently document that atmosphere over Europe during the complete the last glacial period has

* Corresponding author.
E-mail addresses: lisa@gli.cas.cz (L. Lisá), pneruda@mzm.cz (P. Neruda), znerudova@mzm.cz (Z. Nerudová), lnej5536@uni.sydney.edu.au (L. Nejman).

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been permanently dusty. Each of the warm oscillations (D-O, GI) records a similar scenario: 1000 years of relatively stable, cold conditions terminated by an abrupt (less than 10 years) jump to much warmer conditions that persist for 200–400 years, followed by a more gradual transition (50–200 years) back to the conditions that precede the warming event (Dokken et al., 2013). In every case, chronological generalizations of climatic oscillations may lead to mistakes in the regional environmental interpretations. Therefore, the environmental history of specific areas is better revealed by the regional terrestrial record and then linked to the generally accepted scheme where possible. The response of climatic events in the terrestrial record was contingent on various environmental conditions that include geology, landscape morphology, vegetation cover, and the presence of the water. Therefore, individual regions differ significantly in these characteristics, resulting in several chronostratigraphic schemes specific to local regions and local terms for the individual climatic fluctuations. In addition, many of these records are not compatible with recent findings.

The Moravian landscape is an important area for palaeoenvironmental studies from many points of view. During the MIS 3 period, the Moravian landscape consisted of a system of deep valleys and acted as a corridor between the Panonian Basin and the North-European plains that was often used by big mammals as well as by hunter-gatherers (e.g. Van Andel et al., 2003), in particular anatomically modern humans (AMH) (Oliva, 2007; Skiner, 2012; Svoboda, 2006; e.g. Valoch, 1996) who colonized Europe during the middle part of MIS 3 (Conard and Bolus, 2008; Higham et al., 2014; Hublin, 2015; Nejman et al., 2011; Neruda and Nerudová, 2013; Obreht et al., 2017; Svoboda, 2015; Teschler-Nicola, 2006). The upper part of MIS 3 spans two interstadials – Hengelo (~39–36 ^{14}C ka BP, corresponding to D-O 11) and Denekamp (~32–28 ^{14}C ka BP – corresponding to D-O 6 and 7) (Ran, 1990; Van der Hammen et al., 1967), although correlating interstadials with D-O events has not been consistent (compare van der Hammen and Dansgaard in Fig. 1). Correlation of the Hengelo interstadial with ice-core records remains problematic as stated by Vandenberghe and van der Plicht (2016). The regional environmental conditions certainly played a role in human adaptation strategies (Discamps et al., 2011; Lisá et al., 2013; Nerudová and Neruda, 2015; Skiner, 2012; Stewart, 2005) so palaeoenvironmental research is a salient topic. The well preserved and more or less comprehensive sedimentary archives of MIS 3 in Moravia and adjacent countries (mainly Austria) have already been described in studies of open-air loess sequences with palaeopedological records (Antoine et al., 2013; Demek and Kukla, 1969; Haesaerts et al., 2003; Nigst et al., 2009; Rousseau et al., 2013). Cave deposits have been another source of information for chronostratigraphic divisions of the period in question (Kaminská et al., 2005; Krajcarz et al., 2014, 2016; Musil and Valoch, 1966; Valoch, 1989, 2002; Żarski et al., 2017). The chronostratigraphic scheme developed from palaeosol positions (Bodenkomplexes/Pedocomplexes = PK) in loess sections of southern Moravia is still accepted and used today by Czech researchers (Kukla, 1969a, b; Kukla et al., 1961; Smolíková, 1969). Palaeosols at other loess sites are usually interpreted as indicators of landscape stability during these interstadials. In light of new information revealed from marine chronostratigraphy, the PK scheme was shown to be incomplete due to missing palaeosols following erosional events. The PK I soil corresponds to the time range ca. 37 and 31 ka (Frechen et al., 1999) and therefore includes only the Denekamp Interstadial (D-O 6 and 7; Fig. 1). PK I soil in Czech Republic is comparable with palaeosols recorded at other sites such as loess sections at Willendorf and Schwallenbach (Haesaerts et al., 1996; Haesaerts and Teyssandier, 2003; Nigst et al., 2009), Nussloch in the Upper Rhine area (Antoine et al., 2001, 2009), Schwalbenberg in the Middle Rhine Valley (Schirmer, 2016), and possibly Stillfried in eastern Austria. The age of Stillfried B soil (Fink, 1964) is still uncertain (Terhorst et al., 2014). The longer Hengelo interstadial (D-O 11) is missing in this scheme (compare e.g. Andersen et al., 2006; Valoch, 2012). The so-called Bohunician soil defined by Haesaerts and the Podhradem Interstadial defined by Musil and Valoch were inserted into the scheme to fill the gaps in the terrestrial record (Haesaerts, 1985; Musil and Valoch, 1966) (Fig. 1). A number of stratigraphic limitations that vary by location, notable poor preservation of older Early and Middle Pleistocene units and the diversity of local and regional morphological and vegetation expressions and dust accumulation rates was recently well discussed for the Danube loess by Marković et al. (2015).

The effort to anchor regional differences often resulted in local terminological labels that entered common use, often with no critical revisions. The introduction of these terms was usually based on knowledge of the time, and its use ceased later following refinements. The so-called Podhradem Interstadial proposed for Moravia (Czech Republic) is one such example that was intended to designate a warm interstadial during the Weichselian (Würm according to Alpine classification at the time of research) (Musil and Valoch, 1966). The recent multidisciplinary research project (2011–2016) (Nejman et al., 2017, 2018) that continued the 1950s excavation (Musil et al., 1965) has provided an opportunity for a reevaluation of this term. Therefore, the main aim of this paper is the description of the current state of knowledge about MIS 3 in Moravia and to evaluate the relevance of Podhradem Interstadial for regional chronostratigraphy in light of new findings (Fig. 1).

2. Regional setting and history of MIS 3 chronostratigraphical background in Moravia

Pod Hradem Cave is located in the Moravian Karst – a limestone karstic area situated in the southeastern part of Czech Republic, 21 km north-east of Brno (Fig. 2). The small entrance, approximately 2.1 m high and 3 m wide, is oriented to the north-east at a height of 60 m above the valley bottom. The altitude of the cave entrance is 410.6 m and it is part of the 2nd level in the karstic system (Audy et al., 1997). The entrance corridor is infilled by loamy deposits containing archaeological evidence and MIS 3 climatic record (Nejman et al., 2017; Valoch, 1965).

The term Podhradem Interstadial was introduced into the scientific literature in 1966 (Musil and Valoch, 1966) on the basis of the results of an interdisciplinary research project (1956–1959) in Pod Hradem Cave (Musil et al., 1965). Brown palaeosols that extended along the entire stratigraphic profile in the upper section and contained stone artefacts and fauna from warmer periods were singled out for attention. Some of the artefacts were classified as Aurignacian mainly on the basis of their chronostratigraphic position (so called second finding group (Fundgruppe); Valoch, 1965) and attributed to Würm 1/2 (Fig. 3a) (Musil and Valoch, 1966; Valoch, 1966) according to the climatostratigraphic system used at the time (Penck and Brückner, 1909–11). This interpretation was supported by four indirect radiocarbon dates - 33,300 ± 1100 (GrN-848), 33,100 ± 530 (GrN-1724), 29,400 ± 230 (GrN-1735) and 28,200 ± 220 (GrN-1751) ^{14}C years BP (Valoch, 1996; Vogel and Zagwijn, 1967).

Soon after, there was an effort to link the Podhradem Interstadial with the current pedostratigraphic scheme that was created on the basis of the palaeosol positions (Bodenkomplexes/Pedocomplexes) in loess sections of southern Moravia (Kukla, 1969a, b; Kukla et al., 1961; Smolíková, 1969). The key sedimentary section in this scheme is the Dolní Věstonice section (Kukla, 1969a). Pedocomplex (PK) I in the upper part of the Dolní Věstonice brickyard section was correlated with the Stillfried B horizon in Lower Austria (Fink, 1954), which corresponded to the Würm (W) 2/3 Interstadial in

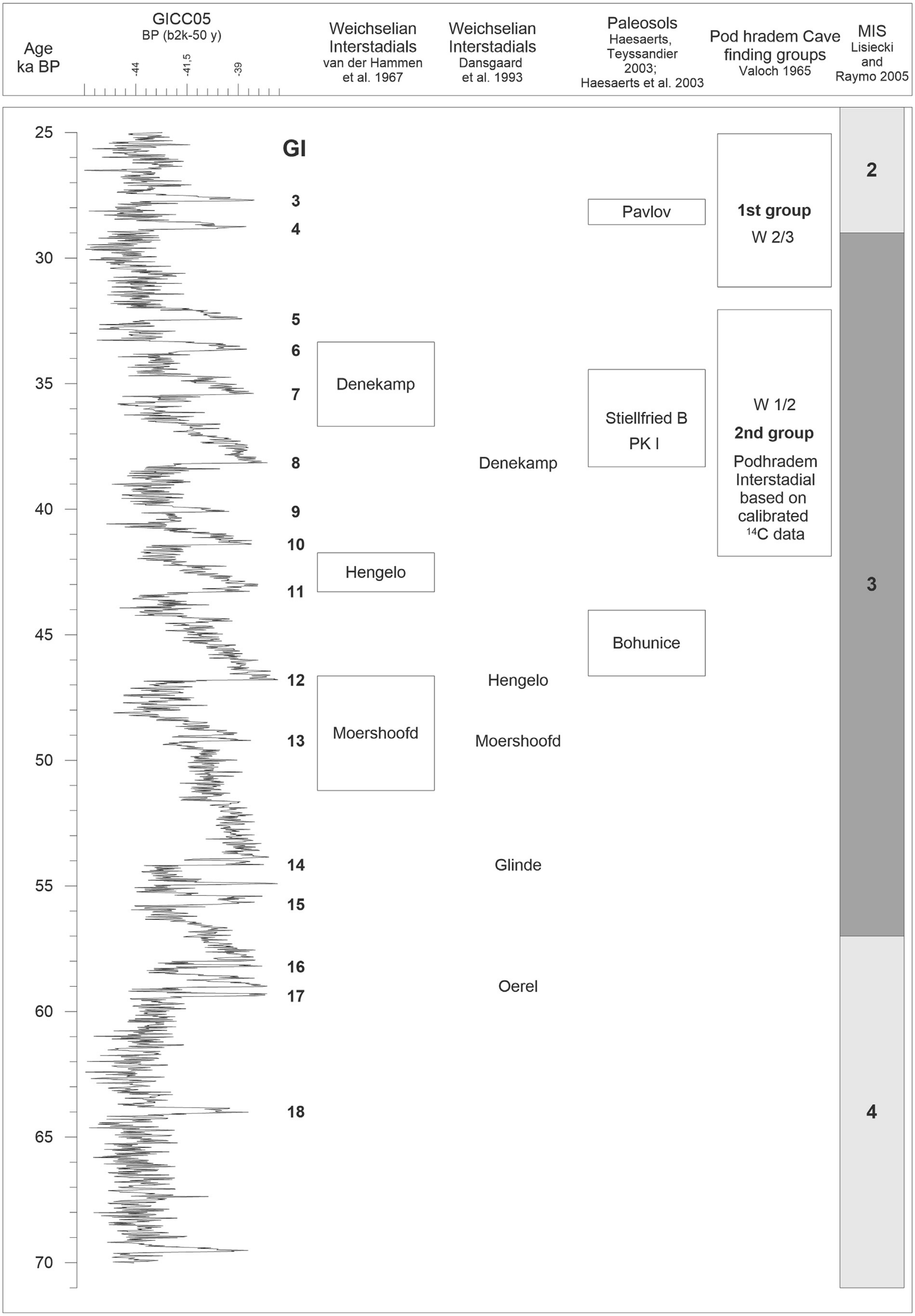

Fig. 1. Climatic division of MIS 3 in Central Europe based on climatic curve GICC05 (Andersen et al., 2006; Svensson et al., 2006), time recalculated to BP; GI (D–O) events (Svensson et al., 2008), interstadials Van der Hammen et al. (1967) and Dansgaard et al. (1993), palaeosol (Haesaerts et al., 2009; Haesaerts and Teyssandier, 2003), MIS (Lisiecki and Raymo, 2005a, 2005b) and chronological position of artefact groups in Pod Hradem Cave (Valoch, 1965).

the scheme of the time (today upper phase of MIS 3). The PK II in the lower part of the Dolní Věstonice section was correlated with climatic phases Brørup and Amersfoort (Andersen, 1961; Zagwijn, 1961) on the basis of stratigraphy and radiocarbon dates (Kukla, 1969b), which ruled out its synchronization with the W 1/2 Interstadial. As the equivalent of the Podhradem Interstadial was missing in the Dolní Věstonice profile, it seemed reasonable to introduce this term (Musil and Valoch, 1966) as a representation of the W 1/2 Interstadial (Valoch, 1971) (Fig. 1).

Later, a hitherto unknown Middle Weichselian soil (not included in Kukla's PK numbering system), was found at Brno-Bohunice (Valoch, 1976), Vedrovice V (Valoch et al., 1993) and at Stránská Skála (Svoboda, 1985, 1991; Valoch et al., 2000). P. Haesaerts termed this horizon 'Bohunician soil' (Haesaerts, 1985). Cultural horizons in sites where this soil was identified yielded Early Upper Palaeolithic (EUP) lithic artefacts. On the basis of current knowledge, the Bohunician soil should be placed stratigraphically between the PK I soil complex (MIS 3) and the PK II which, according to (Kukla, 1969b), corresponded to Brørup and Amersfoort (MIS 5).

The term W 1/2 became defunct. On the basis of new archaeological research, K. Valoch accepted the system of three warm events labelled as Moershoofd (46–44 ^{14}C ka BP), Hengelo (39–36 ^{14}C ka BP) and Denekamp (32–28 ^{14}C ka BP) (Ran, 1990; Van der Hammen et al., 1967), correlated the Podhradem Interstadial with the Hengelo Interstadial (Valoch, 1971), and subsequently with both the Hengelo and Denekamp Interstadials (Valoch, 1989). Recently, Valoch redefined the Podhradem Interstadial (a well-developed soil dated to around 40 ka ^{14}C BP based on the original definition) as an equivalent of the Bohunician soil (Fig. 3d), which also corresponds to the Weichselian (Würmian) Interpleniglacial (Valoch, 2012), correlated with MIS 3. Later, the second author – R. Musil presented a different view. This author points out that the age of archaeological material related to the Bohunician soil cannot be correlated with the Podhradem Interstadial. In his view, it is a different climatic event, which is chronostratigraphically defined (38–32 ka calBP) and positioned between the Bohunice Soil and Denekamp Interstadial (Fig. 3b), and later between Bohunice and Pavlov soils (Fig. 3c).

Inadequate and inconsistent stratigraphic definitions of the Podhradem Interstadial, several changes to its definition by the original authors and other inconsistencies further complicated its use in a pan-European scheme. The term Podhradem Interstadial was then used mainly in the archaeological and anthropological literature (Bricker, 1976; Powell and Klesert, 1980), and less in palaeontological and geological literature (Schütt, 1969). The term is never discussed in detail, and usually linked to the Hengelo Interstadial (Anikovich, 1999; Churchill and Smith, 2000). In addition, the term is frequently misspelled and presented with inconsistencies; Pod hradem Interstadial (Smith et al., 2015), Podhradem Interstadial (Malez et al., 1980), Podrahem Interstadial (Churchill and Smith, 2000) or just even referred to as Podhradem (Bricker, 1976; Smith et al., 1982; Van Andel et al., 2003). The Podhradem Interstadial was used as an analogue for the chronostratigraphic designation of Layer G1 in Vindija Cave (Croatia) (Ahern et al., 2004, 2013; Malez et al., 1980). It was also used in chronostratigrapphic schemes by Kukla (Emiliani et al., 1968) and Musil (2010).

3. Materials and methods

3.1. Recent chronostratigraphy of Pod Hradem Cave

The archaeological excavations in Pod Hradem Cave in 2011–1016 led to a revision of the chronostratigraphy originally proposed by Musil (1965). The cave sediments were subjected to a number of analyses in an attempt to reconstruct environmental conditions that existed in the cave surroundings during MIS 3. The methodological approaches applied so far included detailed archaeological excavations, OSL and ^{14}C dating methods, ICP geochemical analyses, TOC, TN pedogeochemical analyses, grain size analyses, magnetic proxy studies, micromorphology, DNA analyses, micofauna and fauna analysis, anthracological, macroremain and pollen analyses. The sedimentary section was dated and a multiproxy dataset included geochemical, magnetic and micromorphological data (Nejman et al., 2017). Twelve stratigraphic units were identified (Fig. 4) and their environmental properties defined. The main differences between the sedimentary Layers are in the amount and types of limestone clasts, and the presence or absence of charcoal. The uppermost Layer LN-1 corresponds to the Medieval period and the carbonate rich Layer LN-2 below (Fig. 4) chronostratigraphically corresponds to the Atlantic climatic optimum. The brown sediment Layers underlying the carbonate Layer (Layers LN-3–12) correspond to MIS 3 (Nejman et al., 2017). Sediments dating to the LGM were not present in this part of the cave. Based on the microstructures identified by the micromorphological study and other indicators, two main cold climatic events identified in the section correspond to Layers LN-3–4 and LN-7–9 (Fig. 4). Three relatively warmer phases were also identified and include the upper part of Layer LN-3, Layers LN-5–6 and Layers LN-10–12 (Fig. 4). The warmer phases also correlate with increased values of phosphorus, the presence of spongy microstructure and higher concentrations of charcoal fragments (in Layers LN-10 and LN-11 only), higher TOC content and Fe (except in the upper part of the Layer LN-4). Fine grained limestone detritus is ubiquitous in these Layers (except Layers 10–11). Only Layer LN-1 and Layers LN-10 and LN-11 show visible enhancement of frequency dependent magnetic susceptibility, which is a strong indicator of relatively warmer conditions that could correspond to interstadial climate (Nejman et al., 2017).

Unfortunately, the stratigraphy of the cave was shown to be quite complicated and it was not possible to designate a specific Layer that corresponded to the Podhradem Interstadial. Therefore, the macroscopical linkage was summarised from stratigraphic comparisons and radiocarbon dates (Fig. 4). Layer 6 in the 2011–2016 trench dated to 36–41 ka calBP (Nejman et al., 2017) was chosen on the basis of radiocarbon dating as the most probable equivalent of the Podhradem Interstadial (Musil and Valoch, 1966).

4. Methods

4.1. Methods

The background chronostratigraphical data including the geochemical signal used in this paper comes from earlier research (Nejman et al., 2018, 2017) (Nejman et al., 2017, 2018). Stratigraphically speaking, the most likely candidate for the Podhradem Interstadial is Layer LN-6 (Fig. 4) which is approximately 30 cm thick. Micromorphological samples were difficult to collect from the transition to the underlying Layer LN-7 situated below, due to the large number of limestone clasts. Part of Layer LN-7 was finally sampled (to ascertain the presence/absence of micromorphological features related to the Interstadial) during the last field season in 2016. Finally three micromorphological samples were collected using plaster and foam from the eastern wall of square A (one sample collected in 2011) and two samples collected in 2016 from the northern wall of square A). Large thin sections (approximately 140 × 70 mm) were prepared in the laboratory by Julie Boreham, Reach, GB (www.earthslides.com) and examined under plain and cross polarised light at different magnifications (40–800 ×). The descriptions and interpretations followed mainly the formats used

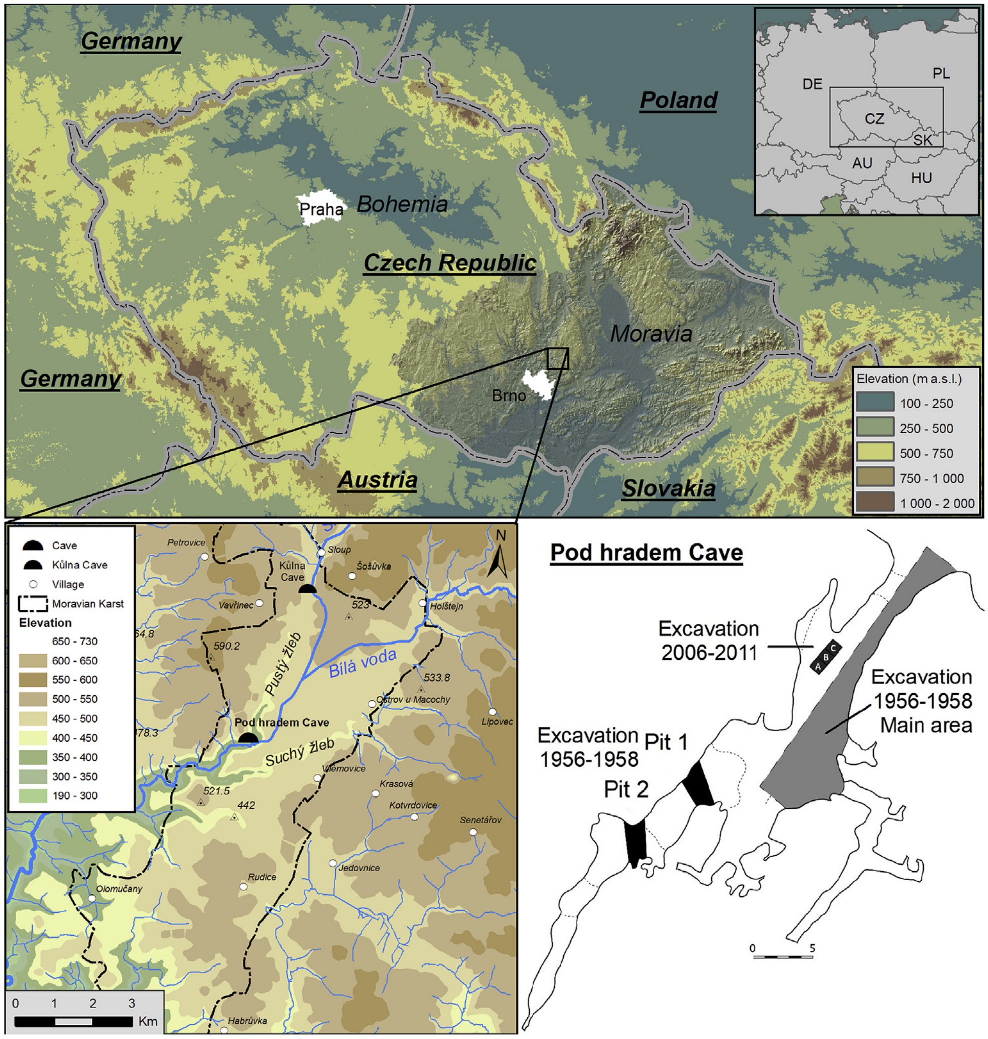

Fig. 2. Position of the site and plan of the cave.

by Stoops (2003) and Stoops et al. (2010).

5. Results

The new geochronological data from Pod Hradem Cave propose, that "Podhradem Interstadial" proposed by Musil and Valoch (1966) is lithologically represented in the front part of the cave by Layer LN-6. This layer is approximately 20–30 cm thick, composed of poorly sorted light brown clayey sandy silt (10YR 4/3 in wet state; 10YR 7/4 in dry state) to strong brown sandy silt (7.5 YR 4/6 in wet state; 10YR 7/4 in dry state), in lower part with angular clast of non-weathered limestone clasts (3–5 cm) and small angular clasts of other petrologies. The hues of this Layer are much lighter than in Layers 8–12 which form the base of the section. The geochemical and other environmental proxies are presented in Nejman et al. (2018, 2017) and the results shown in this paper are based mainly on the micromorphology.

Micromorphologically, the spongy microstructure with irregular voids grades into subangular, blocky microstructure in the upper part of Layer LN-6 (Fig. 5). Brown to orange, slightly phosphatic matrix with carbonate crystals is a typical micromorphological feature of this Layer. Numerous small stains of decomposed organic matter, occasionally to tens μm in diameter, microcharcoal and bone fragments were observed as well as the presence of small Fe-/Mn-oxides nodules (Fig. 5). No silt coatings or rims on clasts were detected.

A sharp transition between Layers LN-6 and LN-7 can be identified by a change in colour, a much higher proportion of larger stone clasts and smaller limestone detritus. This is the only Layer that thins out across the section (Fig. 4) and forms a 'cap' over the lower Layers. The limestone clasts in Layer LN-7 as well as in Layer LN-6 above show distinct weathering crusts with $CaCO_3$ neoformations or overgrowths. Layer LN-7 was dated to 40–42 cal ka BP, which chronologically corresponds to He4 (Henrich event 4) (Nejman et al., 2017). Sedimentological characteristics observed in this sample were similar to Layer LN-6, but the microstructure was highly fragmented consisting of granular microstructure and sharp-edged clasts.

6. Discussion

It is clear that there are problems with the concept of Podhradem Interstadial. First of all, its definition does not meet the standards for a stratotype locality. The term was coined to designate a warm event during the Weichselian glacial period (originally W1/2, for more details see Valoch, 2012), which was not detected in the loess sequences known at the time (Kukla, 1969a, b). In Pod Hradem Cave, this period was described as being represented by so-called

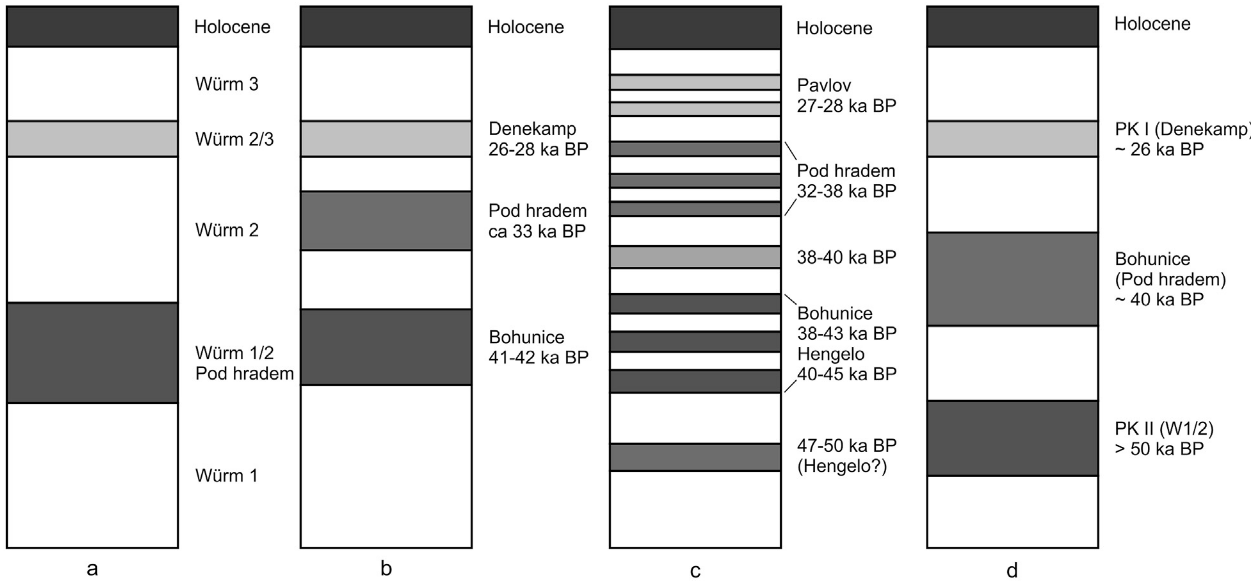

Fig. 3. The development of the ideas about the chronostratigraphic position of Podhradem Interstadial; a – its conception at the time of original research (1956–58) (modified from Musil, 2001); b – stratigraphical position of Podhradem Interstadial within Bohunice and Denekamp Interstadials according to Musil (2001); c – Musil's working scheme of Middle and Late Weichelian stratigraphy (Podhradem Interstadial is divided into three Layers based on the climatic curve) (2001); d – stratigraphic position of Podhradem Interstadial according to Valoch (modified from 2012).

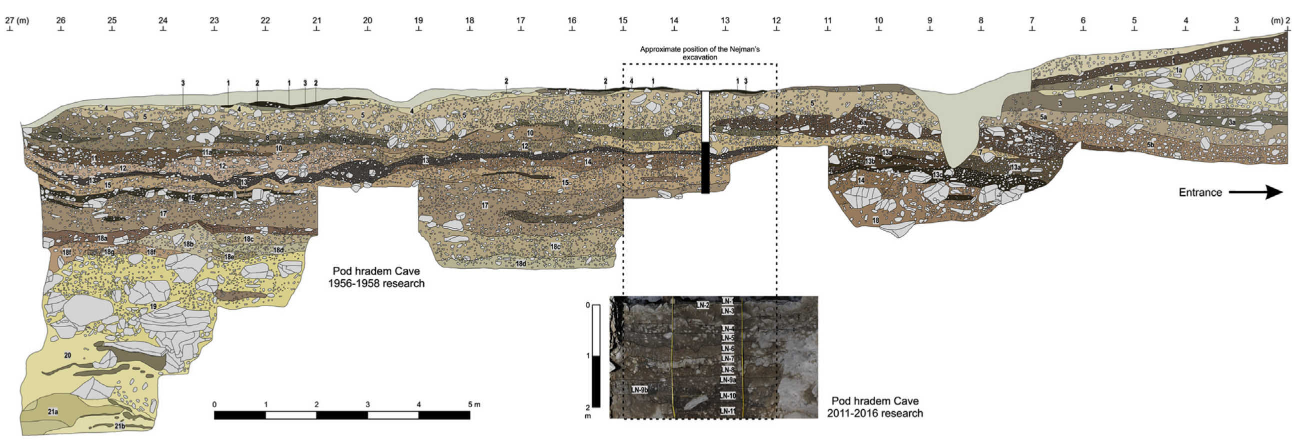

Fig. 4. The comparison of sedimentary sections as backgrounds for the original and revised chronostratigraphy.

"cocoa-brown soils" represented by the sequence of Layers 8–18 divided into two groups (Valoch, 1965). It was hoped that the section would become a stratotype for Moravia and perhaps the surrounding regions. However, when this term was coined, the particular Layer(s) that represented the Podhradem Interstadial was not specified and its lithological and sedimentological characteristics were not clarified (see Musil and Valoch, 1966).

Furthermore, the chronological position of Layers was determined by lithic artefacts and radiocarbon data. In the 'cocoa-brown' soils of the main part of the southern profile (at 21–27 m from the entrance according to the original description), eleven lithic artefacts were dispersed at depths 20–100 cm, but mainly in Layer 8 proposed by Musil and Valoch (1966, note the difference between the labeling in Nejman's and Valoch's excavations). These artefacts were classified as Aurignacian (Valoch, 1965). It was also claimed that this cultural attribution is supported by radiocarbon dates that were obtained from a separate sondage approximately 5 m away. To make matters more complicated, it was not possible to directly correlate the stratigraphy between the two sondages in question. The radiocarbon dates were obtained when the method was in its infancy (original samples were designated with the prefix GrO) (Valoch, 1965) and a subsequent date (GrN-1751) obtained from undisturbed sediment at the base of Pit 1 (see Fig. 2) was significantly younger (Valoch, 1996; Vogel and Zagwijn, 1967) than dates for samples from Layers above (GrN-848, 1724, 1735) (see Nerudová et al., 2012). A subsequent reinterpretation of the Podhradem Interstadial by Musil (2001) used only the two oldest dates, with no reason provided for exclusion of the younger dates. Therefore, it is not possible to use these radiocarbon dating results to chronologically define the Podhradem Interstadial, as Musil proposed.

The clarification of the chronological position, or the lithological composition of the Interstadial was also not possible following the recent excavations (Nejman et al., 2018, 2017, 2013). After comparing the stratigraphic profiles between the 1950s and the 2011–2016 excavations, it can be stated that the originally defined sequence of Layers 8–18 (Valoch, 1965) correspond to Layers LN-6 – LN-11 (Nejman et al., 2017), while the multidisciplinary results have indicated two warm and one cold event. The most likely

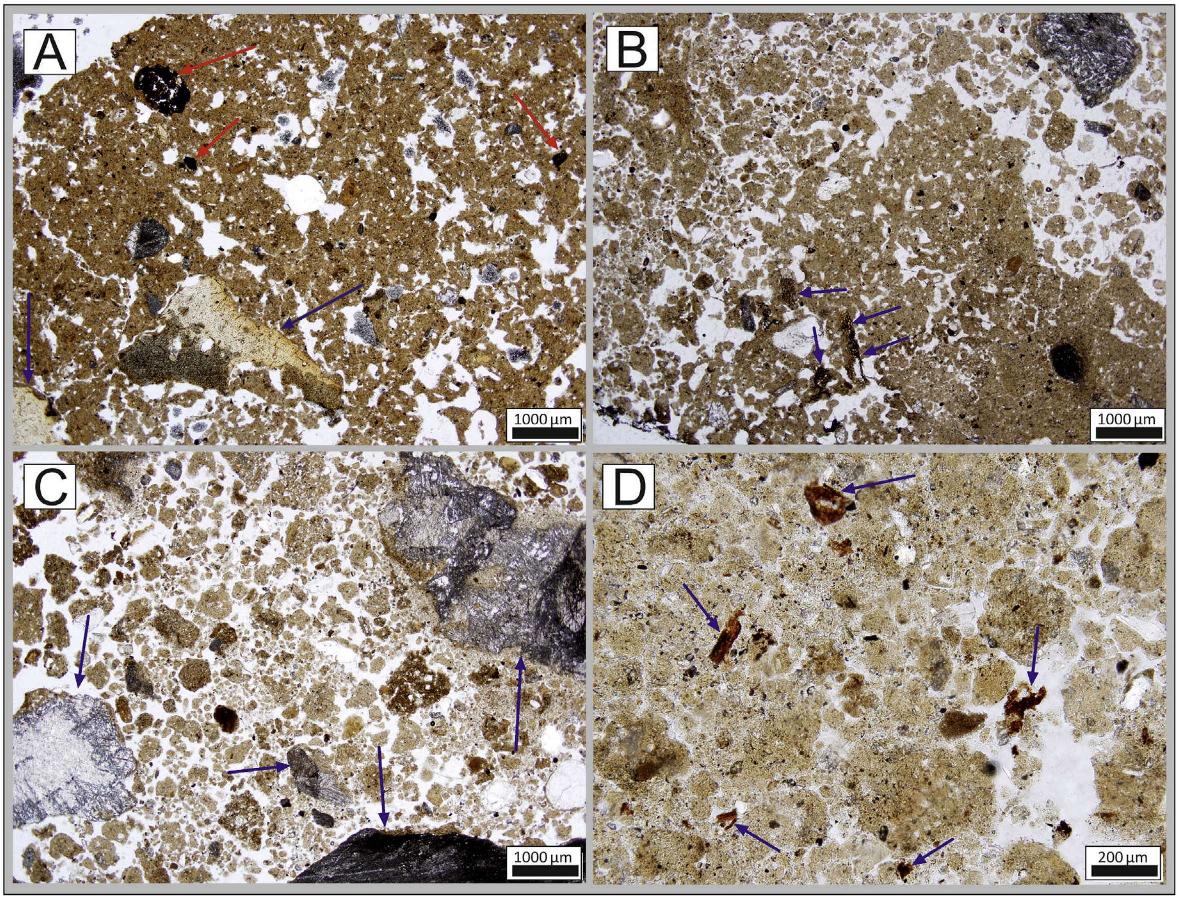

Fig. 5. Micromorphological features observed in Layer 6; A – spongy microstructure of the material taken from the eastern wall of square A. Blue arrows point to the bone fragments, red arrows point to partly decomposed or decomposed organic matter (photo was taken in PPL – plane polarized light); B – complex microstructure of the material taken from the northern wall of square A; spongy microstructure can be observed on the right side of the image and granular microstructure on the left side of the image; blue arrows points to fragments of burned bones (PPL); C - well developed granular microstructure of the material collected from the northern wall of square A; blue arrows points to the different types of limestone clasts; D – partly decomposed or decomposed fragments of organic matter visible in layer 6 (PPL). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

candidates that would correspond to the Podhradem Interstadial as it was originally understood are the newly defined Layer LN-6 and partly also Layer LN-7. This conclusion is also supported by the cultural finds and dating (Nejman et al., 2017).

The sediment formation processes in Pod Hradem Cave were complex and this is also true for Layer LN-6, which is the most likely candidate for the Pod Hradem Interstadial. The lithological characteristics of Layer LN-6 are a result of complex processes that are related to the formation of Layer LN-7. The following scenario may account for the seemingly disparate features of Layer LN-6. During the formation of Layer LN-7, accumulating bones on the hard crust of the undulating cave floor surface were only partially incorporated into the surface and most remained on top of it. During the subsequent formation of Layer LN-6, the climate became more favourable, and guano and fine detritus were being deposited onto the undulated surface of Layer LN-7, gradually forming another sedimentary Layer. As sedimentation proceeded and sedimentary material infilled empty spaces (these spaces also originated from thawing of ice lenses) between the bones that accumulated during the preceding cold period, stratigraphic mixing of bones of different ages and sediments could have occurred. The geochemical signal for Layer LN-6 does not generally show significantly high values of elements typical for the warmer period, i.e. elements connected with more intense weathering and accumulation of fine grained organic matter. Despite this finding, the stratigraphic depth around 1 m, i.e. the transition into Layer LN-5 above and Layer LN-7 below, is crucial from several points of view: while the transition into Layer LN-7 is macroscopically visible only in the dramatically increased number of clasts, the transition into Layer LN-5 shows significant trends (Nejman et al., 2018). The Ca/Mg ratio decreases dramatically with the transition into Layer LN-5 as do the values of phosphorus, Ca, TOC and TN. Other elements have consistent values or show a slight increase (Al, Fe, enhancement of magnetic susceptibility signal) probably reflecting a change in sediment provenance, the intensity of weathering, or both (Nejman et al., 2018). Bokhorst et al. (2009) suggest that the variations of Ca, Mg and Sr in loess sequences are not likely to depend on the change in provenance. On the other hand the estimation of silicate Ca in calcareous material, as common in most loess, may lead to biased weathering records using these indices (Buggle et al., 2011). The interpretation of pollen and faunal remains also proved to be problematic when dividing the stratigraphic horizons into 'warm' and "cold" events (Nejman et al., 2018). A high percentage of the carrot family (Daucaceae - which frequently occurred in pollen clumps) – over 15% - in Layer LN-6, is unusual. The presence of *Alnus* is consistent with a warmer climate, whereas the presence of *Pinus cembra* charcoal indicates a cooler climate. Marked changes in pollen spectra between Layers LN-6 and LN-7 (predominance of Asteroideae and decreased diversity of pollen in Layers LN-7–11) are probably related to changes in chemical processes affecting the

sediments. All microfauna species are indicative of a glacial landscape except for one woodland specimen (*Sorex araneus*). The combination of warmer and cooler climate indicators could be a sign of a generally cool climate with some short warm interstadials. Alternatively, they could indicate non-analogue taxonomic combinations – a common feature of MIS 3 taxonomic assemblages (Stewart et al., 2003).

The sedimentological record in this cave is one of the best preserved cave record of MIS 3 in Central Europe (Nejman et al., 2018, 2017), but as is typical for terrestrial records (particularly cave sequences), it contains gaps. The soil complex, originally described as W 1/2 Interstadial "cocoa brown soils (Layers 8–18)" (Valoch, 1965) that includes the Podhradem Interstadial in its upper part, can be generally interpreted as the Vistulian Interpleniglacial sedimentation. The new excavations show that the whole complex of soil sediments represents more than one climatic event. Unfortunately, the original definition did not clearly stipulate which Layers represent the Podhradem Interstadial; therefore additional dating is not possible.

We can interpret the Podhradem Interstadial in two ways:

1 If we assume that the Podhradem Interstadial represents the Hengelo Interstadial (Valoch, 2012), then Bohunician soil is its equivalent in the open sites. However, given that individual Layers in caves are often highly variable sedimentologically, it may be more fruitful to use open loess sites for regional schemes as, for example, Hasaerts did for the Willendorf Interstadial defined on the basis of a loess sequence in Willendorf II in Lower Austria (Haesaerts and Teyssandier, 2003).
2 If we accept that the Podhradem Interstadial chronologically corresponds to a 38–32 ka calBP time span (Musil, 2001), then we would need to explain why climatic fluctuations have not been identified in loess sequences of open sites of central and southern Moravia as for example Dolní Věstonice (Antoine et al., 2013), Dobšice (Hošek et al., 2015) or Předmostí (Lisá et al., 2014). Such climatic fluctuations have been identified, for example, in the GICC05 record, which also correlates with the climatic records captured in Greenland ice cores (Andersen et al., 2006; Svensson et al., 2006). Comparable sediments have not been identified in other caves in the Moravian Karst, or even in other regions. We do not have an adequate explanation, but even if we did, open sites are more suitable for definitions of climatic events. Pod Hradem Cave is not a suitable stratotype site as many factors have contributed to the formation of the sediments. Applying stratigraphic principles to achieve a definition is not possible even using the data collected during the recent 2011–2016 excavation.

It is not appropriate to define an interstadial using radiocarbon dates only, which in Pod Hradem Cave are quite disparate anyway (Nejman et al., 2017; Nerudová et al., 2012). The large statistical errors often have longer duration than the climatic fluctuations themselves, as defined by, for example, the global climatostratigrafic curve GICC05 (Andersen et al., 2006; Svensson et al., 2006). Although Musil subdivided the Podhradem Interstadial into three warm events (2001), he did so on the basis of climatic curves from Greenland ice cores, and not on the basis of the sedimentological record. Most of the authors connect the Podhradem Interstadial with Hengelo interstadial. The situation is even more complicated using the comparison with these old terms as pointed out by Vandenberghe and van der Plicht (2016). They state: "We have re-investigated the ^{14}C dates of the classic Hengelo interstadial obtained for the typesite, and conclude that it dates to the range 36,000–38,600 BP. Using the calibration curve IntCal13, which now covers this age range, the absolute date for Hengelo is derived as 42,350–41,380 calBP (at 1-sigma confidence). This corresponds best with the interstadials GI-10 or 11 on the Greenland ice core timescale. This correlation is anyway not representing the longest warmest interstadial as appears from the ice-core and marine records, as widely assumed in the literature". In the light of this new interpretation the Hengelo Interstadial seems to be the older event more likely connected to layers 10-12 at Pod Hradem Cave (Nejman et al., 2017).

The central issue is whether to define regional climatic fluctuations using terrestrial records, in particular using cave sediments that tend to be incomplete and may not reflect the outside environment. Modern climatic curves such as those obtained from Greenland ice cores are relatively complete, well-dated and offer far more detail than the terrestrial records. In addition, the proposed classification of individual climatic fluctuations (Dansgaard/Oeschger Events – Heinrich Events, Greenland Interstadials – Greenland Stadials) is today universally accepted, which allows interregional comparisons (Vandenberghe and van der Plicht, 2016). For this reason, the term Podhradem Interstadial is redundant and should not be used in future chronostratigraphic schemes.

7. Conclusions

The origin of the term Pod Hradem Interstadial term possessed historical value in the development of our knowledge of the Middle Weichselian. It was fairly clear from early on that equivalents of this stratotype are difficult to detect not only in other caves, but also in open sites. Its codification became therefore problematic and the definition of this term was also problematic. The new excavations in Pod Hradem Cave in 2011–2016 identified the stratigraphic horizon comparable to the Podhradem Interstadial based on radiocarbon dating (i.e. correlated with the Hengelo Interstadial). Relatively recently developed methodological approaches confirmed that this horizon has micromorphological properties pointing to an interstadial climate. On the other hand, its lithological characteristics are very problematic and can be easily confused with other stratigraphic horizons in the cave that developed during previous or subsequent interstadial conditions. In our opinion, the term Podhradem Interstadial is now redundant and climatic changes during the Weichselian glaciations can be more adequately and clearly described and characterized using the global climatostratigraphic system.

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